LINE-REVERSAL MEASUREMENTS OF EXCITATION AND ELECTRON TEMPERATURE IN A SHOCK TUBE

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by

W. R. S. Garton
Imperial College, London, England

and

W. H. Parkinson and E. M. Reeves
Harvard College Observatory
Cambridge, Massachusetts

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ABSTRACT

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The spectral line-reversal method has been applied to determine population-temperatures within an (argon-calcium) plasma, generated by a reflected aerodynamic shock. The measurements have been made simultaneously on (a) normal bound-bound Ca I lines, (b) lines involving strongly auto-ionizing levels. The agreement of the two sets of values identifies the electron-temperature with the temperature characterizing the populations of the bound excited-states, giving improved confidence in the existence of complete thermal equilibrium in the reflected shock.

Author

The spectral-line reversal method has been previously applied to transitions between normal bound electronic states of neutral atoms, ions or molecules, (Gaydon and Hurle 1963; Charatis and Wilkerson 1962; Parkinson and Reeves 1964). The technique yields the "excitation" or "population" temperature between the pair of states concerned, but has the great advantage over methods which depend only on relative intensities of emission or absorption lines, of avoiding involvement with transition probability values, as well as the complex issues which arise when account has to be taken of partition function termination and ionization potential depression, (Garton, Parkinson and Reeves 1964). In earlier experiments with shock-heated gases we have observed (Parkinson and Reeves loc. cit.) the line reversal temperature to be independent of the excitation energy, and on that basis have suggested the gas to be in thermal equilibrium.

We have now made further reversal-temperature measurements on lines possessing strongly autoionizing upper states, i.e., states lying in the continua above the normal series terms converging on the ground state of the ion. The population of an autoionizing level depends on the electron density and electron temperature. The autoionization-broadened line may, in fact, be regarded as a resonance in an ionization continuum (Fano 1961; Fano and Cooper 1965), the selection rules for autoionization requiring that the upper level can find an adjacent continuum of the same J and parity, and for LS-coupling the same L- and S-values. Departures from LS-coupling relax the latter requirement. If reversal-temperature measurements are made on the same plasma, respectively with lines which do and do not have autoionizing upper states, and identical values are found, it is a safe conclusion that the electron temperature has been measured and found equal to the temperature characterizing the Boltzmann distribution of the normal bound states. In the measurements here reported, the two reversal temperatures did agree within experimental error, and the assumption of a good approach to thermal equilibrium in the shock-heated gas is thereby strengthened.

Not many autoionized lines have been identified in the wavelength region above 2800Å where line-reversal measurements are possible. Fortunately, however, the autoionizing transition 3d4p $^3F^\circ$ - 3d4d ^3G in neutral calcium has been identified at λ6362, λ6343 and λ6318. The normal transition 4p ^3P_o - 4d ^3D of Ca I also provides a suitable line at 4425.4Å. With the method of shock-heating powdered solids, calcium vapour can easily be introduced into the reflected shock region and simultaneous line-reversal temperature measurements can be made with one of the autoionized λ6350 lines and the normal λ4425 Ca I line. Since the ^3G upper level of the autoionizing transition lies in the continuum, the triplet of λ6350 has a lower level which is approximately 4.5 electron volts above the ground state. A temperature of approximately 6000°K in the reflected shock was required to populate the ^3G state sufficiently for the line to be observed in emission.

The experimental arrangement for these measurements was very similar to that reported earlier (Parkinson and Reeves loc. cit.). A Xenon flash tube (EGG FX-12 provided the background continuum for both atomic lines. Light from the same region of the reflected shock and from the FX-12 was divided by a beam-splitter, and images were formed on the entrance slits of two F/9 half-meter Jarrell-Ash scanning spectrometers. An RCA 1P28 photomultiplier was used to detect the 4425Å radiation, and an RCA 4463 recorded the autoionized line, with entrance and exit slits of both monochromators set at approximately 20 microns.

The optical system was calibrated with a Phillips tungsten-filament standard lamp. The shock waves were produced in a pressure-driven stainless-steel shock tube with a 9-ft. channel, 3-ft. driving section with uniform 2 inch square cross section. Hydrogen at 165 psi was used to generate the shocks in pure argon at an initial pressure of 10 Torr.

The measured temperatures and emissivities for the two wavelengths are listed in Table I. The average difference between the pairs of measured temperatures is approximately 50°K, and is within our estimated experimental error of 1.5%. To verify the estimate of the experimental error we made several runs with both monochromators on the 4425Å line and observed a temperature difference of about 90°K.

Because the calcium atoms were introduced into the reflected shock by the powdered solid technique, we were concerned about the uniformity in the distribution of powder and the concentration in the boundary layer. We observed, for optically thick lines, that the boundary layer in the shock tube could affect the temperature by as much as 300° in 6500°. For this reason, the emissivity was kept less than one so that the temperature that was measured would represent an average temperature across the shock tube. The distribution of atoms would, of course, be more uniform in an experiment where the atomic species could be introduced into the channel gas as a volatile vapour, and it would then be possible to compute the temperature. With the powdered solid technique one cannot calculate the temperature behind the reflected shock wave because of the unknown amounts of energy required to vaporize, dissociate, and excite the actual number of calcium atoms in the test gas. Attempts at this calculation have indicated that the energy involved would reduce the temperature from that of the pure argon case by approximately 15%.

We are continuing these experiments on other autoionized lines from atoms introduced to the shock as powdered solids and as volatile compounds. With the confirmation of thermodynamic equilibrium in the shock tube, it will be possible to measure the absolute intensity in the centers of autoionized lines. This method then offers the possibility of using the shock tube as an absolute standard of radiation at wavelengths where autoionized lines are observed.

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TABLE I

Line	6362.4Å		4425Å		
	Temp. (°K)	ϵ	Temp. (°K)	ϵ	ΔT(°K)
	5760	0.76	5890	0.42	-130
	6258	0.70	6262	0.40	- 4
	6390	0.45	6360	0.633	+ 30
	6740	0.62	6798	0.76	- 58
	6800	0.36	6767	0.59	+ 33

Average ΔT = 51°

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